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RESEARCH MEMORANDUM

THE EFFECT OF SOME SURFACE ROUGHNESS ELEMENTS ON THE
DRAG OF A BODY OF REVOLUTION AT SUPERSONIC SPEEDS

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON

November 24, 1954

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RESEARCH MEMORANDUM

THE EFFECT OF SOME SURFACE ROUGHNESS ELEMENTS ON THE
DRAG OF A BODY OF REVOLUTION AT SUPERSONIC SPEEDS

By Russell N. Hopko

SUMMARY

The effects of some rivets, butt joints, and lap joints on the drag of a body of revolution at zero lift at supersonic Mach numbers to 2.1 have been obtained in free flight with rocket-propelled models. The butt joints tested showed no significant effects on the drag. Rivets and lap joints increased the drag of the smooth-body configuration, the forward-facing lap joints contributing the greatest increases.

INTRODUCTION

The possibility of reducing construction costs of any article is always of importance to the manufacturer. To this end, aircraft and missile manufacturers have expressed interest in the effects on drag of surface irregularities due to practical construction techniques used on aircraft and missiles flying at supersonic speeds inasmuch as unnecessary effort may be expended in smoothing a surface for the purpose of drag reduction.

Previous investigations to determine the effects of roughness elements on drag at supersonic speeds have been made with the NACA RM-10 missile (ref. 1). The present investigation is concerned with the drag increases due to rivets, butt joints, and lap joints at supersonic speeds. Preliminary results were reported in reference 2. The Mach number range of the present tests was from 0.9 to 2.1. The corresponding range in Reynolds number, based on body length, was from 20×10^6 to 60×10^6 . The flight tests were conducted at the Langley Pilotless Aircraft Research Station at Wallops Island, Va.

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SYMBOLS

C_D drag coefficient, $\frac{\text{Drag}}{qS}$

$\Delta C_D = \frac{\text{Drag increment due to roughness}}{qS}$

c wing chord

q dynamic pressure

S frontal area of basic body, 0.136 sq ft

l body length

R Reynolds number, based on body length

MODELS AND TESTS

The general arrangement of the models is shown in figure 1. A photograph of the test models which were constructed of aluminum alloy is shown in figure 2. The bodies were 56 inches in length with pointed ogival noses of fineness ratio 3.5 and conical afterbodies. Body coordinates for the smooth body (model 1) are shown in table I. Surface conditions were varied at four body stations: 18.5, 29.0, 39.5, and 50.2. At these stations model 2 had staggered double rows of 1/8-inch-diameter AN 456 (modified brazier head) rivets with a longitudinal spacing of 5/8 inch. Each row had 16 rivets except the forward row at station 50.2 which had 12. Model 3 had open butt joints which were 0.0625 inch wide and 0.064 inch deep. Models 4 and 5 had, respectively, 0.032- and 0.064-inch-high backward-facing lap joints with conical sections between the joints and had maximum diameters of 5.000 inches. Models 6 and 7, respectively, had 0.032- and 0.064-inch-high forward-facing lap joints with conical sections between the joints. Models 6 and 7, respectively, had maximum diameters of 5.064 and 5.128 inches. Prior to launching, all models were polished.

The models were accelerated to a Mach number of approximately 2.1 by means of a two-stage propulsion system. A photograph of one of the models on its launcher is shown in figure 3.

During flight the models were tracked with a CW Doppler radar unit to determine the velocity and with a modified SCR 584 radar set to determine the flight path. The variation of Reynolds number with Mach number

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is shown in figure 4. Atmospheric data at altitude were obtained by radiosonde. The velocity history corrected for winds was differentiated to obtain the acceleration history from which the drag was computed.

The total errors are estimated to be within the following limits:

M	±0.005
C_D	±0.005

RESULTS AND DISCUSSION

The variation of the total drag coefficient based on the smooth-body frontal area with Mach number is given as figure 5.

Simulated butt joints, 0.0625-inch-wide and 0.064-inch-deep groove, showed no appreciable effect on the total drag. An increase in the butt width, however, would cause the drag to increase. It may be recalled from reference 1 that other types of roughness (simulated cast surface, waviness of the surface) also showed no appreciable effect on the total drag.

Each of the other surface irregularities of this investigation increased the drag coefficients over those of the smooth-body configuration. The drag increment did not vary appreciably with Mach number so that the percentage increase in drag due to the irregularities increased as the test Mach number was increased.

At a Mach number of 1.1, the Reynolds number based on the length to the first roughness station is 6.6×10^6 . The boundary layer being assumed to be turbulent at all roughness stations, an estimate (using the method of ref. 3) of the drag penalty associated with lap joints was made which assumes only a change in pressure drag effected. The estimated and measured incremental drag variations are shown in figure 6.

It is felt that the estimations are sufficient for short-range coasting missiles. There is the possibility, as with model 7, that successive roughness elements may thicken the boundary layer sufficiently to reduce the effectiveness of the most rearward elements. In this case, the estimate of the drag penalties would be conservative.

CONCLUSIONS

A free-flight investigation was made with rocket-propelled models to determine the effects of rivets, butt joints, and lap joints on the

drag of a body of revolution at zero lift at supersonic Mach numbers to 2.1. The following conclusions were indicated:

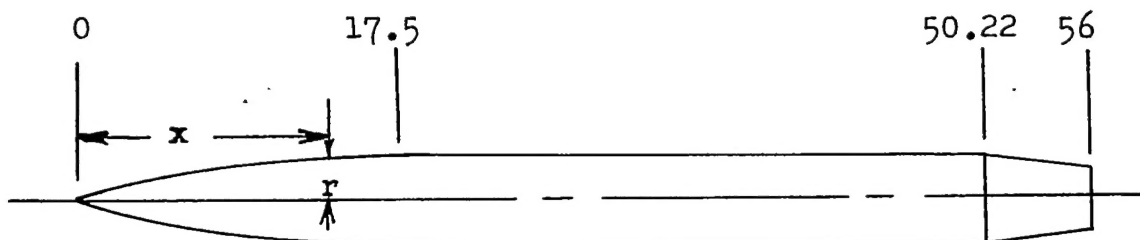
1. The open butt joints tested showed no appreciable effect on the total drag.
2. The rivets and lap joints tested increased the drag of the smooth-body configuration, the forward-facing lap joints contributing the greatest increases.
3. Estimates of the drag penalties due to the lap joints are sufficient for small-range missiles.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., September 8, 1954.

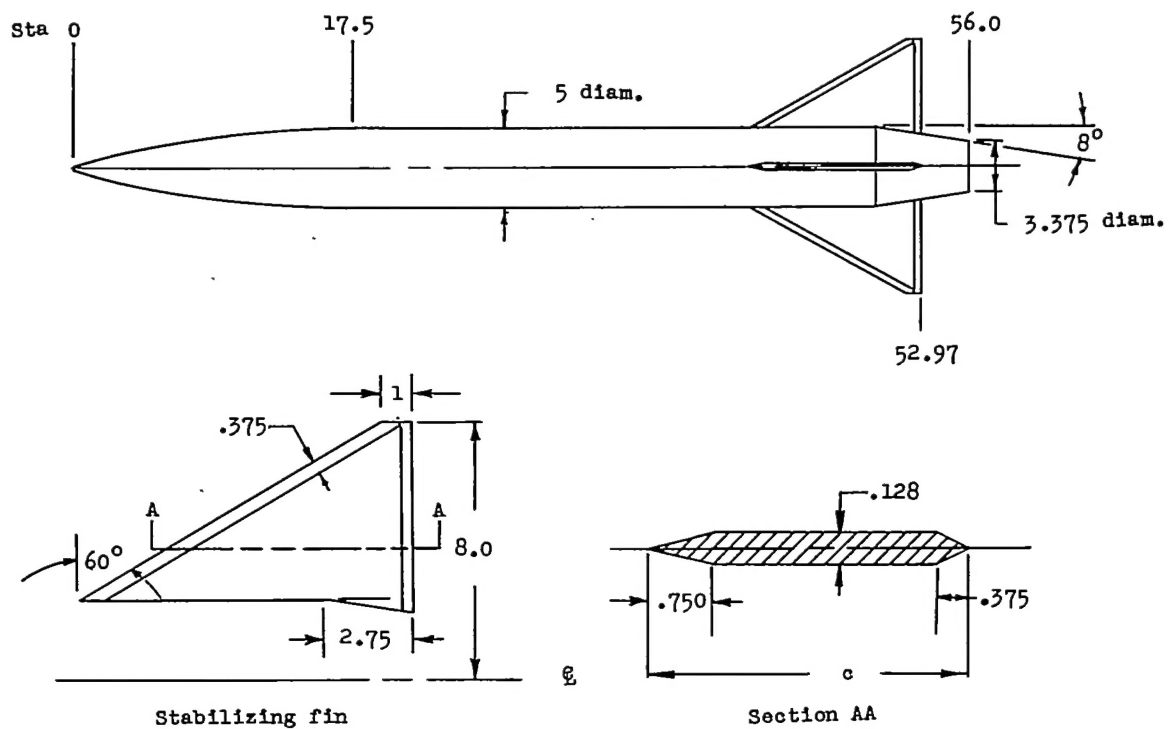
REFERENCES

1. Jackson, H. Herbert: Flight Measurements of the Effects of Surface Condition on the Supersonic Drag of Fin-Stabilized Parabolic Bodies of Revolution. NACA RM L52B26, 1952.
2. Hopko, Russell N.: Preliminary Free-Flight Investigation of the Effects of Rivets and Lap Joints on the Drag of Bodies at Zero Lift at Supersonic Mach Numbers to 2.1. NACA RM L52F09, 1952.
3. Love, Eugene S.: The Base Pressure at Supersonic Speeds on Two-Dimensional Airfoils and Bodies of Revolution (With and Without Fins) Having Turbulent Boundary Layers. NACA RM L53C02, 1953.

TABLE I
BODY COORDINATES FOR MODEL I

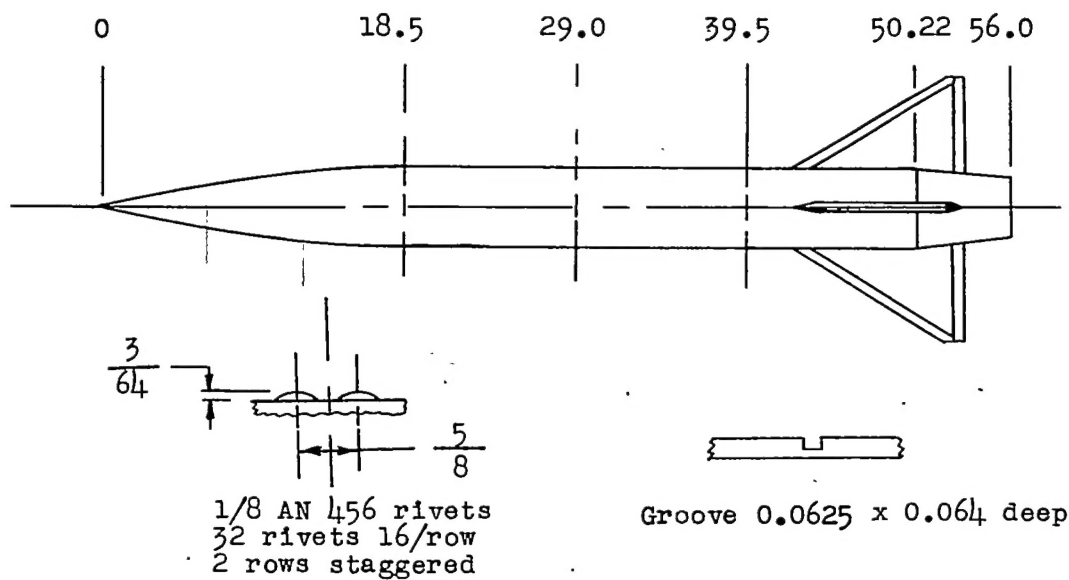


Body coordinates	
x , in.	r , in.
0	0
1.00	.250
2.00	.480
3.00	.710
4.25	.975
5.00	1.130
7.50	1.570
10.00	1.955
12.50	2.252
15.00	2.429
17.50	2.500
20.50	2.500
50.22	2.500
56.00	1.688



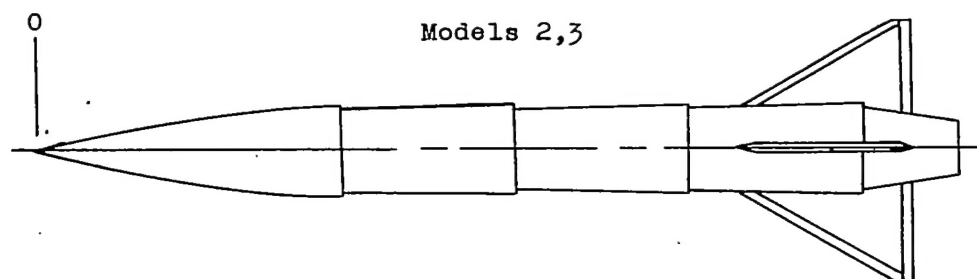
Model 1

Figure 1.- General arrangement of test vehicle. All dimensions are in inches.



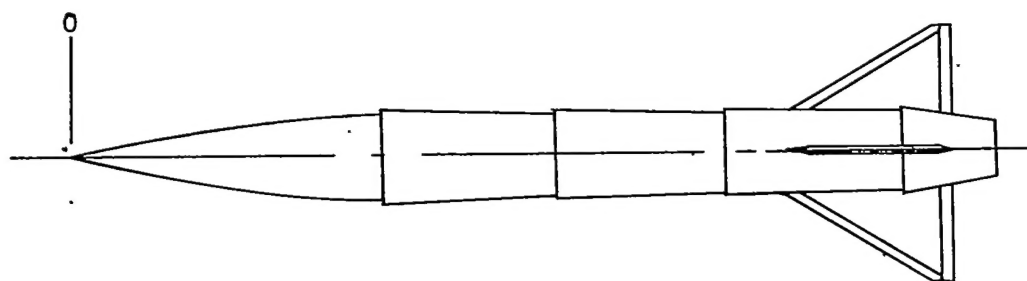
Model 2

Model 3



0.032 and 0.064 backward-facing lap joints
max diam., 5.000

Models 4,5

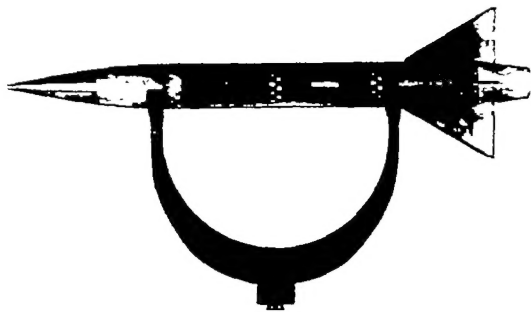


0.032 and 0.064 forward-facing lap joints
Model 6 max diam., 5.064 Model 7 max diam., 5.128

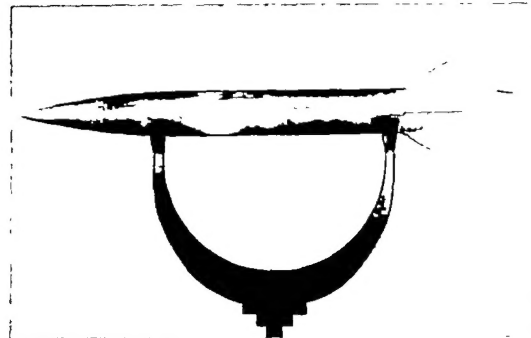
Models 6,7

Figure 1.- Concluded.

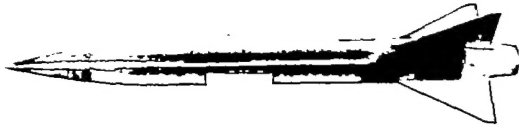
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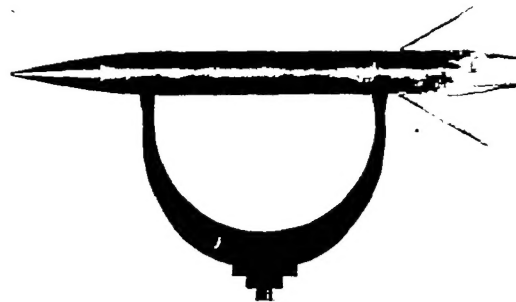
Model 2



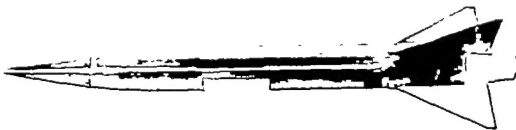
Model 3



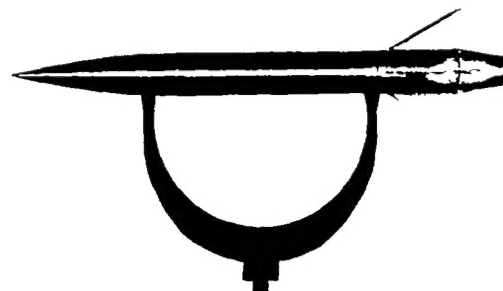
Model 4



Model 5



Model 6

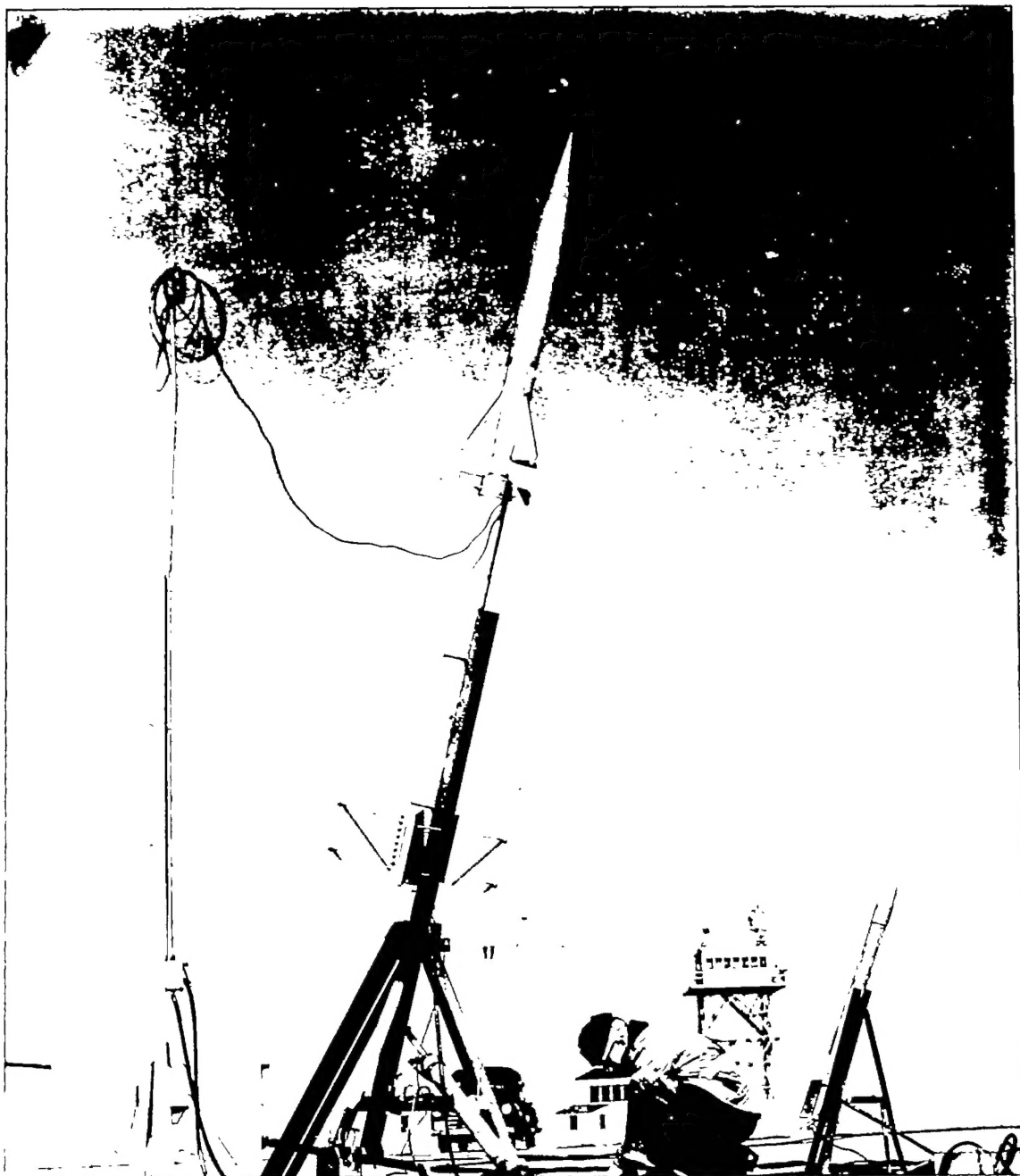


Model 7

Figure 2.- Photograph of test models.

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Figure 3.- One model in launching position.

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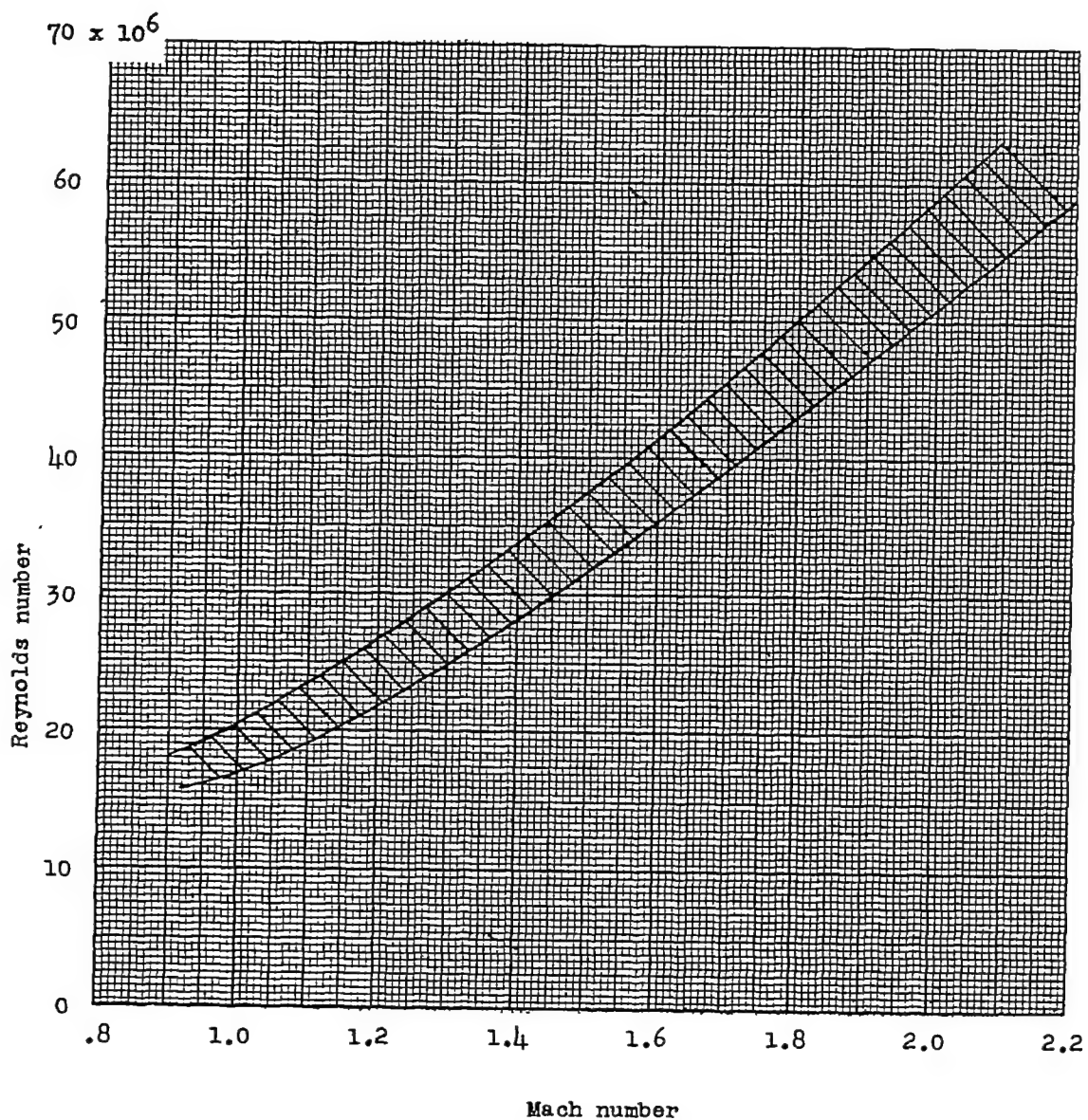
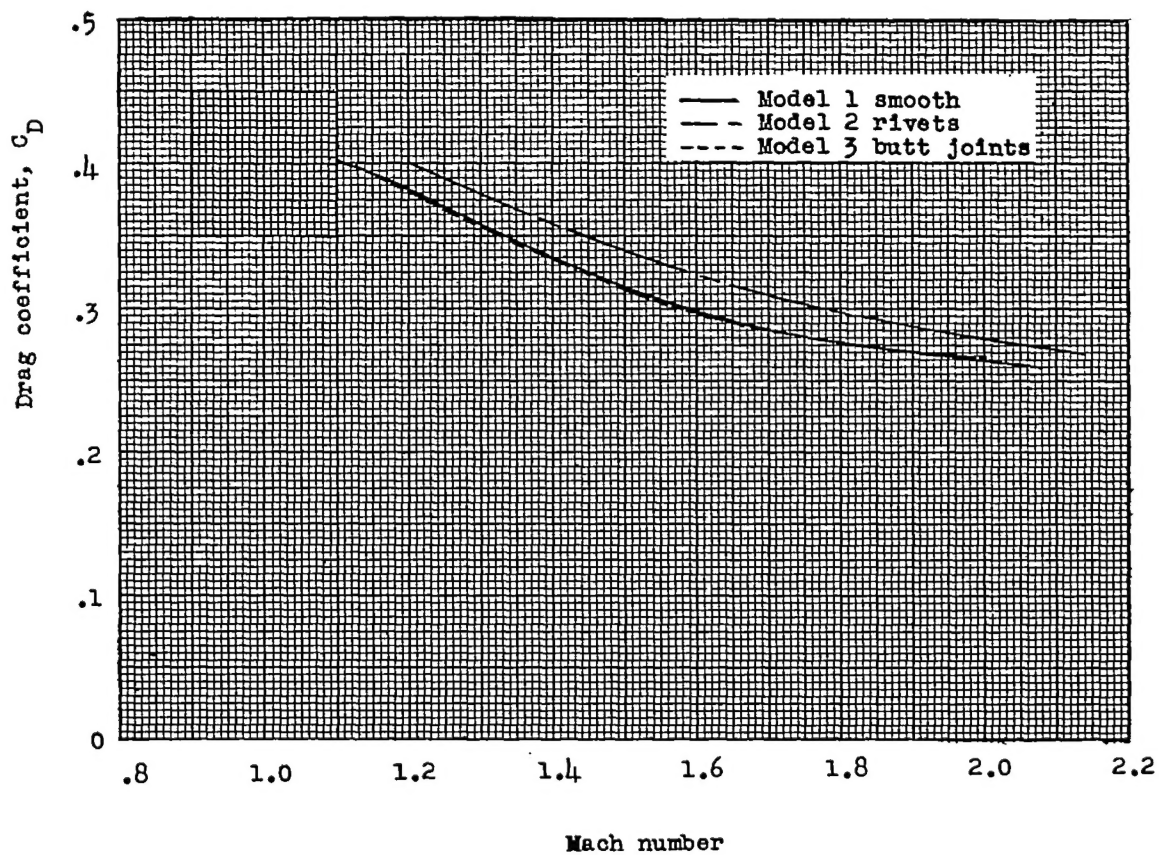


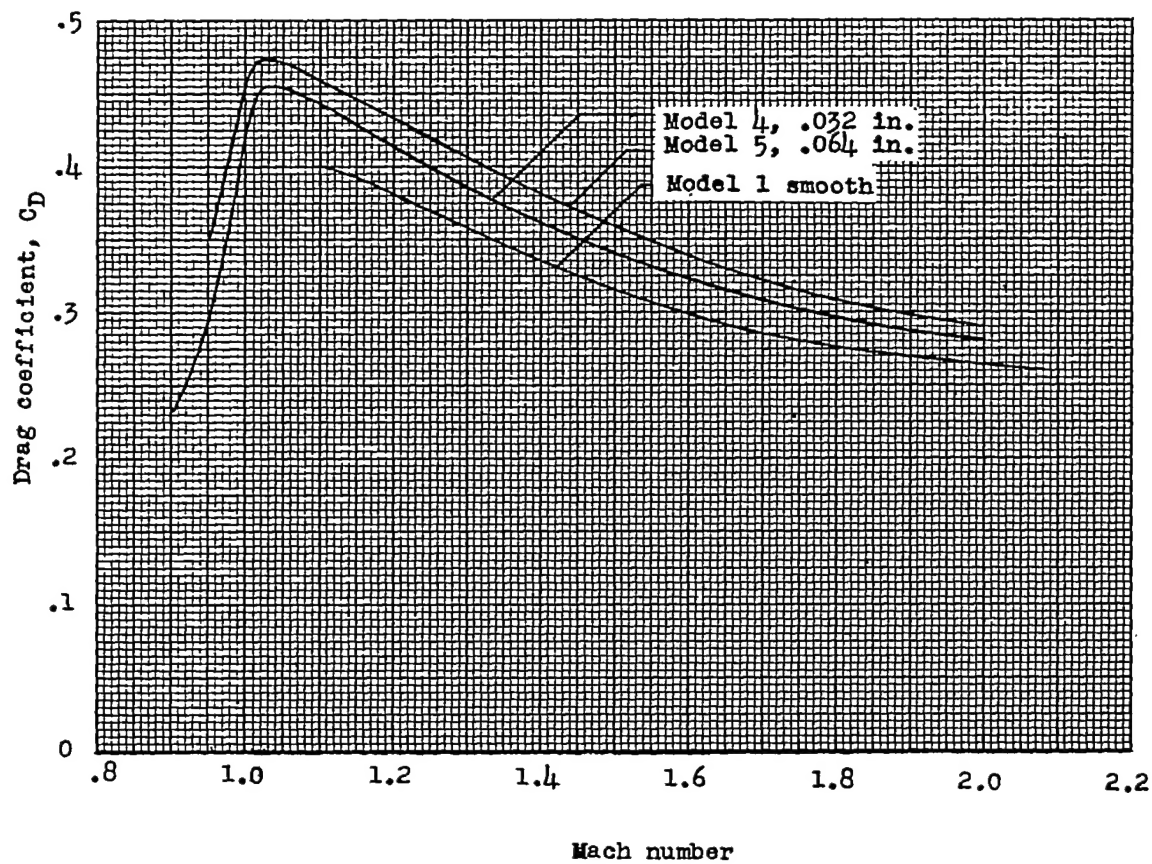
Figure 4.- Variation of Reynolds number, based on body length, with Mach number.

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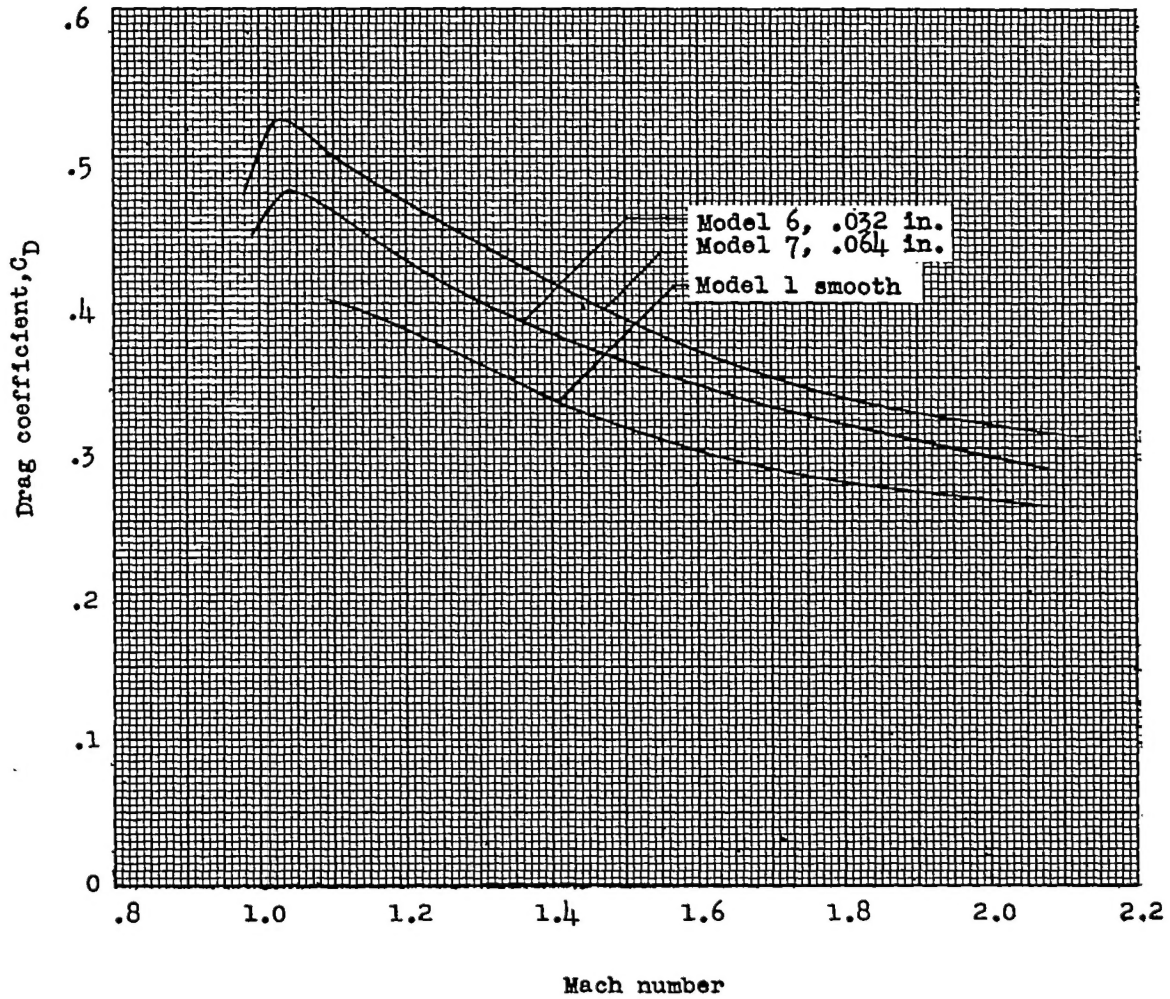
(a) Rivets and butt joints.

Figure 5.- Variation of drag coefficient with Mach number.



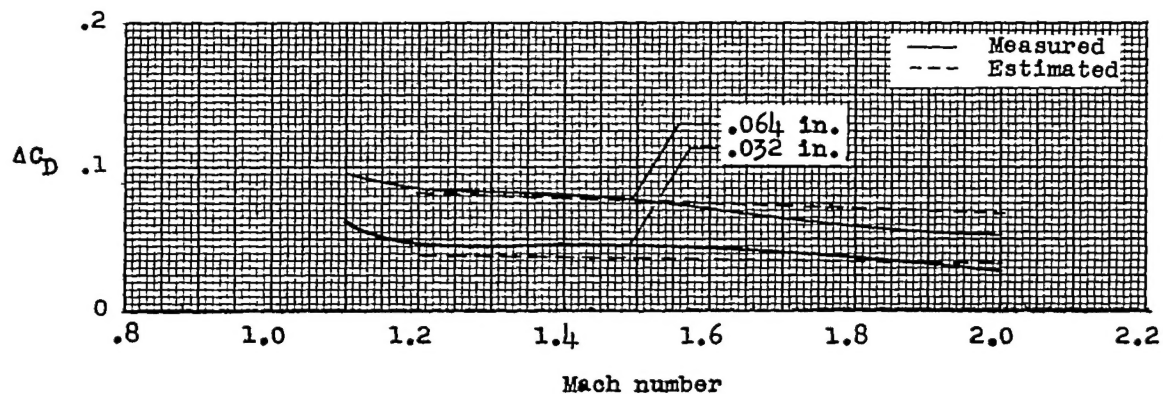
(b) Backward-facing lap joints.

Figure 5.- Continued.

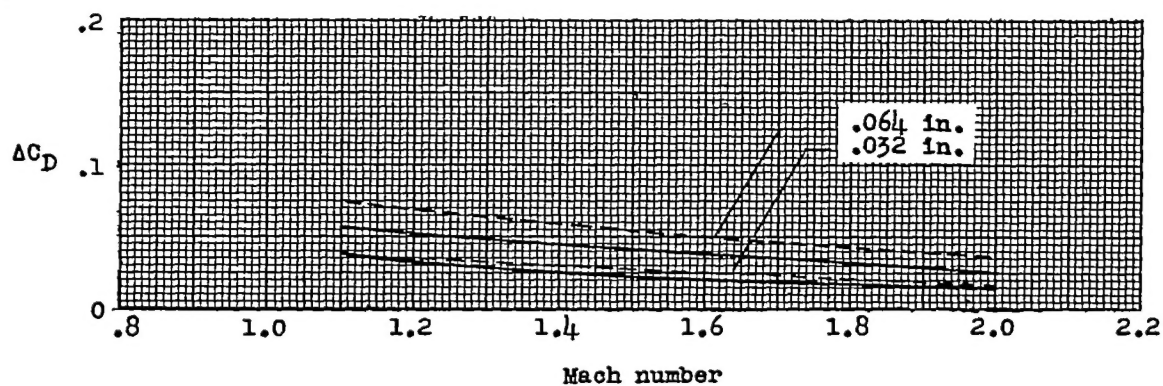


(c) Forward-facing lap joints.

Figure 5.- Concluded.



(a) Forward-facing lap joints.



(b) Backward-facing lap joints.

Figure 6.- Variation of drag increment due to lap joints.